MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EME4026 – TRIBOLOGY
(ME)

7 MARCH 2020
9:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENT

1. This Question paper consists of 10 pages including cover page with **4 Questions** only.

2. Attempt **FOUR** out of **FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

4. A list of useful equations and charts are given as **Appendix A**.

Question 1

(a)   **Explain** and illustrate the four mechanisms involved in ploughing friction.

[12 marks]

(b)   A hard conical asperity of roughness angle 13° is scratched along a soft flat surface to produce a groove of 0.8 mm width. The measured coefficient of friction is 0.27. **Determine** the abrasive and adhesive component of friction coefficient and the groove depth.

[13 marks]

Question 2

In a pin-on-disc wear experiment, the flat face of a brass annulus pin having an outside diameter of 20 mm and inside diameter of 10 mm is rubbed on a flat steel disc of diameter 120 mm at a distance of 40 mm away from their centers. The test conditions and wear results are given as follows:

Normal load = 20 N
Rotational speed of the disc = 90 rpm
Sliding duration = 120 hours
Hardness of brass = 0.8 Gpa
Hardness of steel = 2.5 Gpa
Density of brass = 8.5 Mg/m^3
Density of steel = 7.8 Mg/m^3
Mass loss of brass = 40 mg
Mass loss of steel = 2 mg

i.   **Sketch** the wear track on the disc and **determine** the sliding distance.

[9 marks]

ii.   **Determine** the adhesive wear coefficients for both materials.

[8 marks]

iii.   **Calculate** wear depths of the brass pin and steel disc.

[8 marks]

Continued...

Question 3

(a)   State four causes of waviness in a surface.   [4 marks]

(b)   A hydrodynamic bearing with L/D ratio = 0.25 is designed to operate at journal speed of 1380 rpm and subject to a radial load of 2000 N. The radial clearance is 0.06 mm. Assuming SAE 10 oil is used and its operating temperature is 50°C, determine the following:

      i.   Sommerfeld number.   [4 marks]

      ii.   Minimum oil film thickness, h_o.   [3 marks]

      iii.   Coefficient of friction, f.   [3 marks]

      iv.   Maximum film pressure, P_{max}.   [3 marks]

      v.   Angle between load direction and minimum film thickness, Φ [2 marks]

(c)   Derive an expression that relate Petroff's equation to Sommerfeld number.

[6 marks]

Question 4

(a)   An automobile engine has five main bearings, each 2.5 inch in diameter and 1 inch long. The diametral clearance is 00015 inch. By using Petroff's equation, estimate the power loss per bearing at 3600 rpm if SAE 30 oil is used, with an average oil film temperature of 180°F.

[13 marks]

(b)   Explain and show schematically the convergence wedge action in journal bearings.

[12 marks]

Continued...

Appendix A

- Adhesion friction force $\qquad F_a = A_r\,\tau_a$
- Adhesion friction coefficient for dry contact:

$$\mu_a = \frac{F_a}{W} = \frac{A_r.\tau_a}{W} = \frac{A_r.\tau_a}{P_r.A_r} = \frac{\tau_a}{P_r}$$

- The friction coefficient in terms of surface roughness in elastic region,

$$\mu_a \approx \frac{3.2(\tau_a)}{E^*\left(\dfrac{\sigma_p}{R_p}\right)^{1/2}}, \quad \frac{1}{E^*} = \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2}, \quad \sigma_p = \sqrt{\sigma_{p1}^2 + \sigma_{p2}^2}, \quad \text{and} \quad \frac{1}{R_p} = \frac{1}{R_{P1}} + \frac{1}{R_{P2}}$$

- Degree of plasticity. $\qquad \varphi = \left(E^*/H\right)\left(\sigma_p/R_p\right)^{1/2}$

- Ploughing friction due to a circular cone hard asperity

$$\mu_p = \frac{F_f}{W} = \frac{2d}{\pi r} = \frac{2\tan\theta}{\pi}, \quad \text{or} \quad \alpha = 90^\circ - \theta, \qquad \mu_p = \frac{2\cot\alpha}{\pi}$$

- Ploughing friction due to a spherical hard asperity

$$\mu_p = \frac{F_f}{W} = \frac{P_y.A_p}{P_y.A_l} = \frac{A_p}{A_l} = \frac{2}{3\pi}.\frac{2r}{R}$$

- Ploughing friction due to a spherical asperity for a relatively large groove width as compared to sphere radius:

$$\mu_p = \frac{2}{\pi}\left\{\left(\frac{R}{r}\right)^2 \sin^{-1}\left(\frac{r}{R}\right) - \sqrt{\left(\frac{R}{r}\right)^2 - 1}\right\}$$

- Ploughing friction due to a cylindrical asperity:

  Case-1: the cylindrical placed transversely over a softer surface, $\mu_p = \sqrt{\dfrac{1}{2(R/d) - 1}}$

  Case-2: the cylindrical placed upright over a softer surface, $\qquad \mu_p = (2/\pi)\dfrac{d}{R}$

- Holm equation for adhesive wear, $\qquad V_w = \dfrac{k_{adh}.W.x}{H}$ *Plastic contacts*

- Archard equation for adhesive wear, $\qquad V_w \propto \dfrac{W.x}{H} = k_{adh}\dfrac{W.x}{H}$ *Plastic contacts*

- Bhushan equation for adhesive wear, $\qquad V_w = \bar{k}_{adh}\dfrac{W.x}{E^*\sqrt{(\sigma_p/R_p)}}$ *elastic contacts*

- Rabinowicz's equation for abrasive wear, $\qquad V_w = \dfrac{2W.x.\tan\theta}{\pi.H}$

- An abrasive expression similar to Archard's equation, $V_w = \dfrac{K_{abr}.W.x}{H}$

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Petroff's Equation

Friction torque

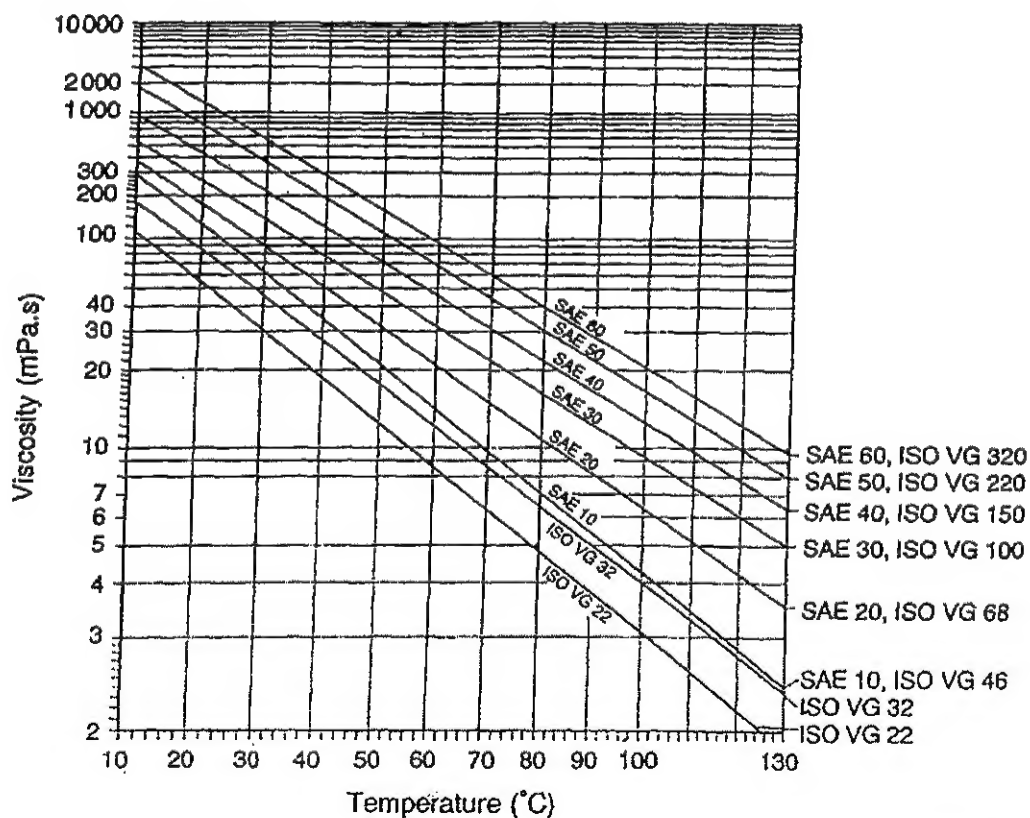$$T_f = \frac{4\pi^2 . \eta . n . L . R^3}{C} = f . W . R = f(D . L . P) R$$

Coefficient of friction

$$f = 2\pi^2 \left(\frac{\eta n}{P}\right) . \left(\frac{R}{C}\right)$$

Power loss (watt)

$$H_v = 2\pi . T_{f_{(N.m)}} . n_{rps}$$

Sommerfeld number

$$S = \left(\frac{R}{C}\right)^2 \frac{\mu n}{P}$$

Average film pressure

$$P = \frac{W}{DL}$$

Chart A1 – Variation of absolute viscosity with temperature for various lubricants

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Chart A2 – Viscosity versus temperature curves for typical SAE graded oil
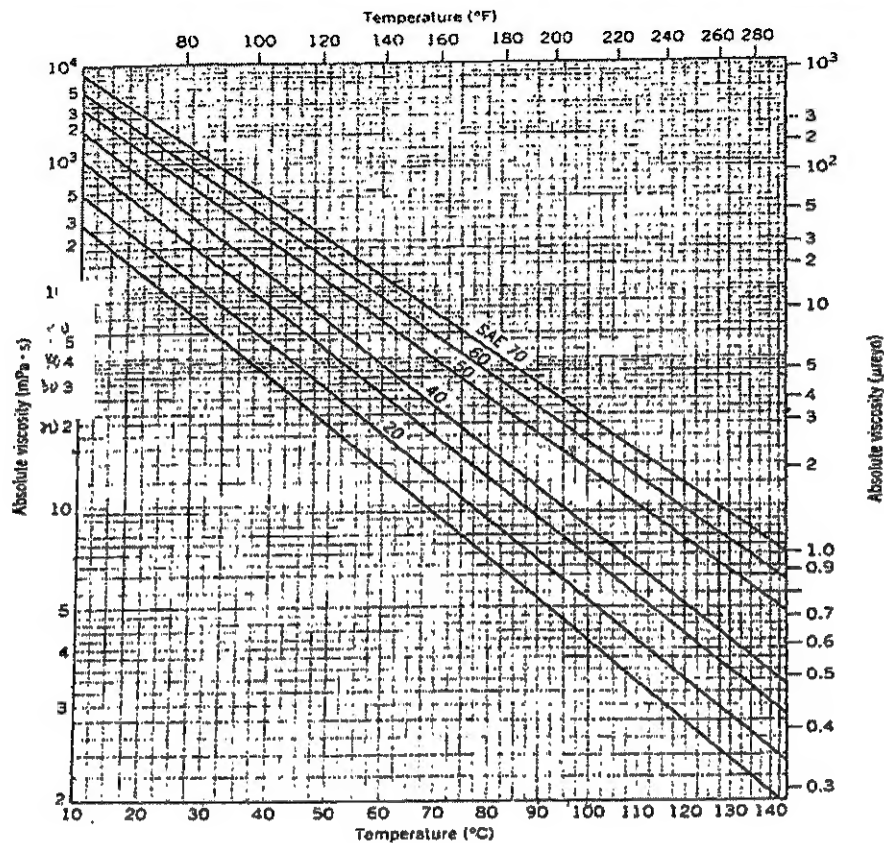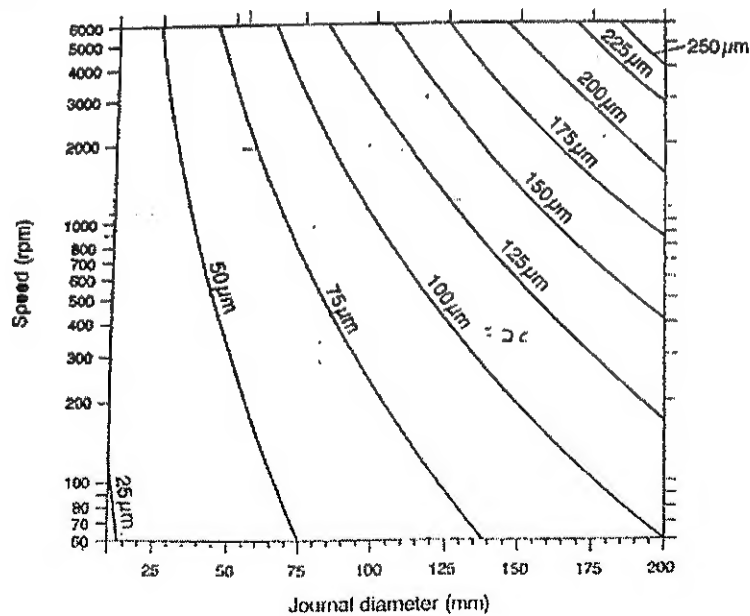

Chart A3 – Recommended values of diametral clearance (2c) for steadily loaded journal bearing

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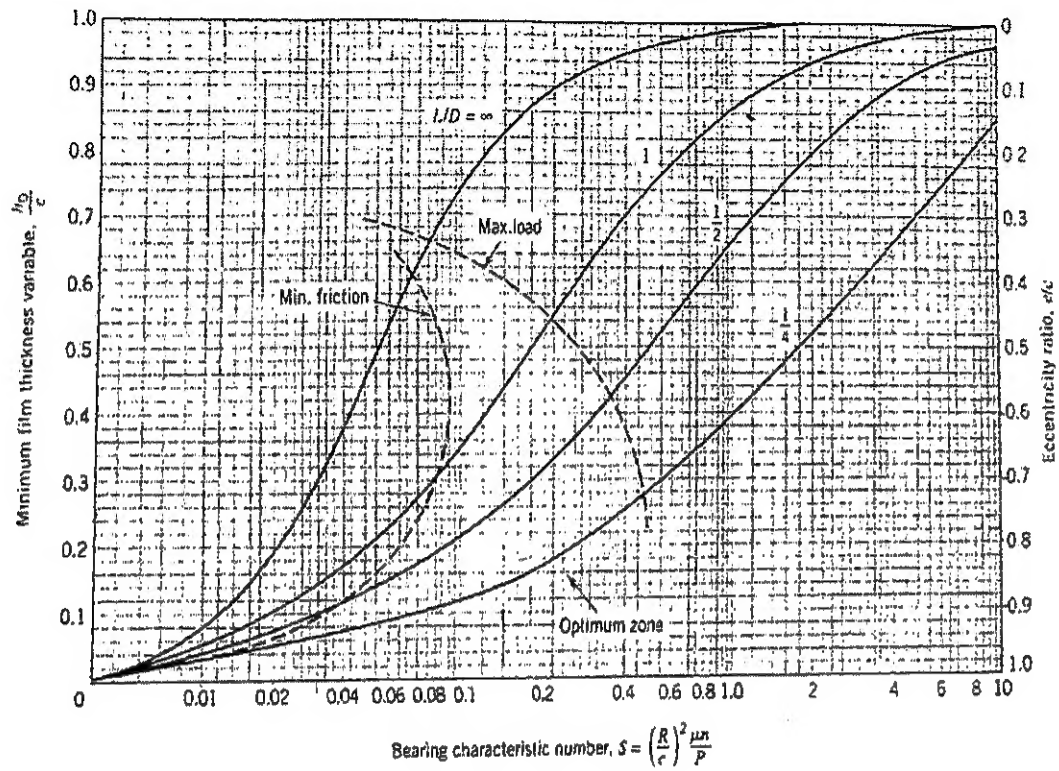
Chart A4 – Minimum film thickness variable

Chart showing minimum film thickness variable $\frac{h_0}{c}$ (vertical axis, left) versus bearing characteristic number, $S = \left(\frac{R}{c}\right)^2 \frac{\mu n}{P}$ (horizontal axis), with eccentricity ratio e/c on the right vertical axis. Curves labelled $L/D = \infty$, 1, $\frac{1}{2}$, $\frac{1}{4}$ and regions marked Max. load, Min. friction, and Optimum zone.

Chart A5 – Friction coefficient variable

Chart plotting Coefficient of friction variable, $\frac{R}{c}f$ (y-axis, from 1 to 200) against Bearing characteristic number, $S = \left(\frac{R}{c}\right)^2 \frac{\mu n}{P}$ (x-axis, from 0 to 10). Curves labelled $L/D = \frac{1}{4}$, $\frac{1}{2}$, 1, and ∞.
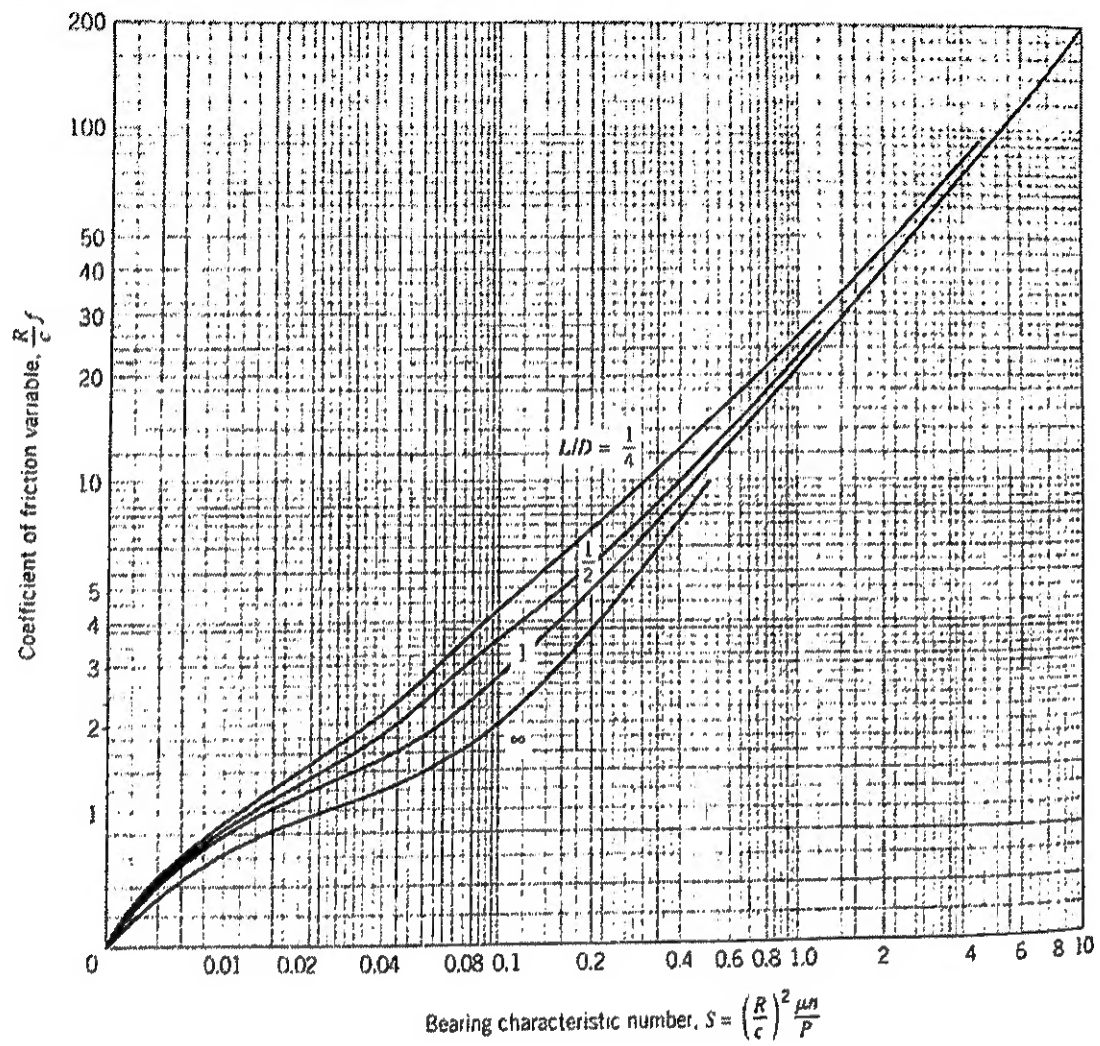
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Chart A6 – Maximum film pressure

Minimum film pressure ratio, $\dfrac{P}{p_{max}}$ (gage) vs. Bearing characteristic number, $S = \left(\dfrac{R}{c}\right)^2 \dfrac{\mu n}{P}$

$L/D = \infty$, 1, $\dfrac{1}{2}$, $\dfrac{1}{4}$
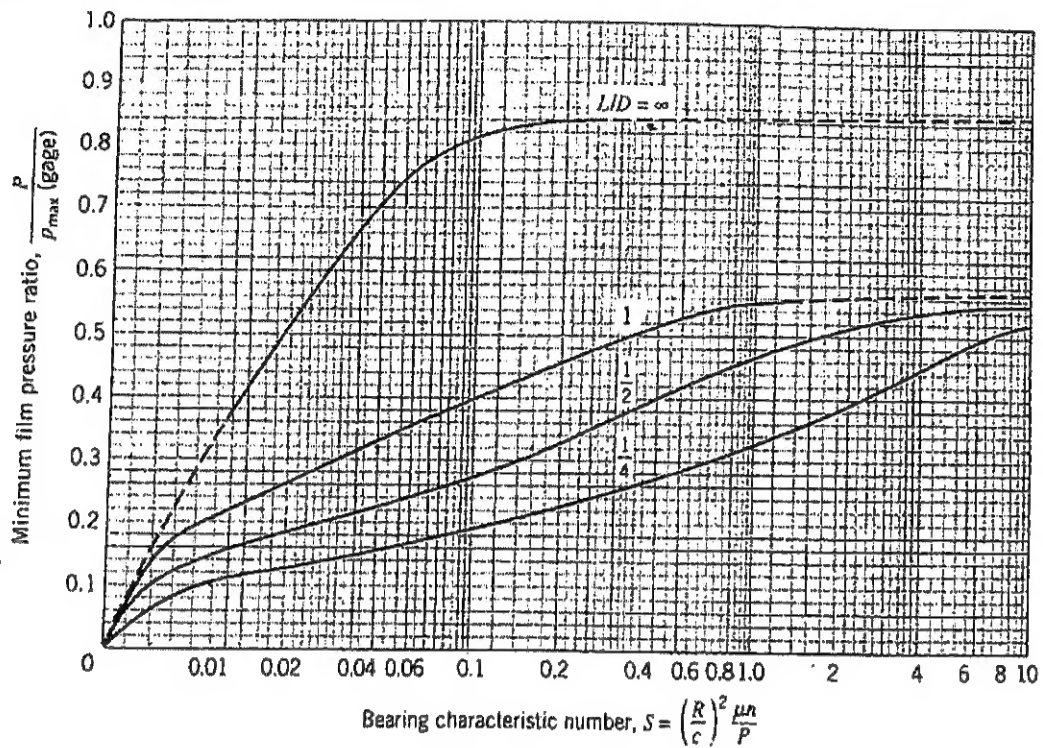
Chart A7 – Position of the minimum film thickness

Position of minimum film thickness, ϕ (deg°) vs. Bearing characteristic number, $S = \left(\dfrac{R}{c}\right)^2 \dfrac{\mu n}{P}$

$L/D = \infty$, 1, $\dfrac{1}{2}$, $\dfrac{1}{4}$
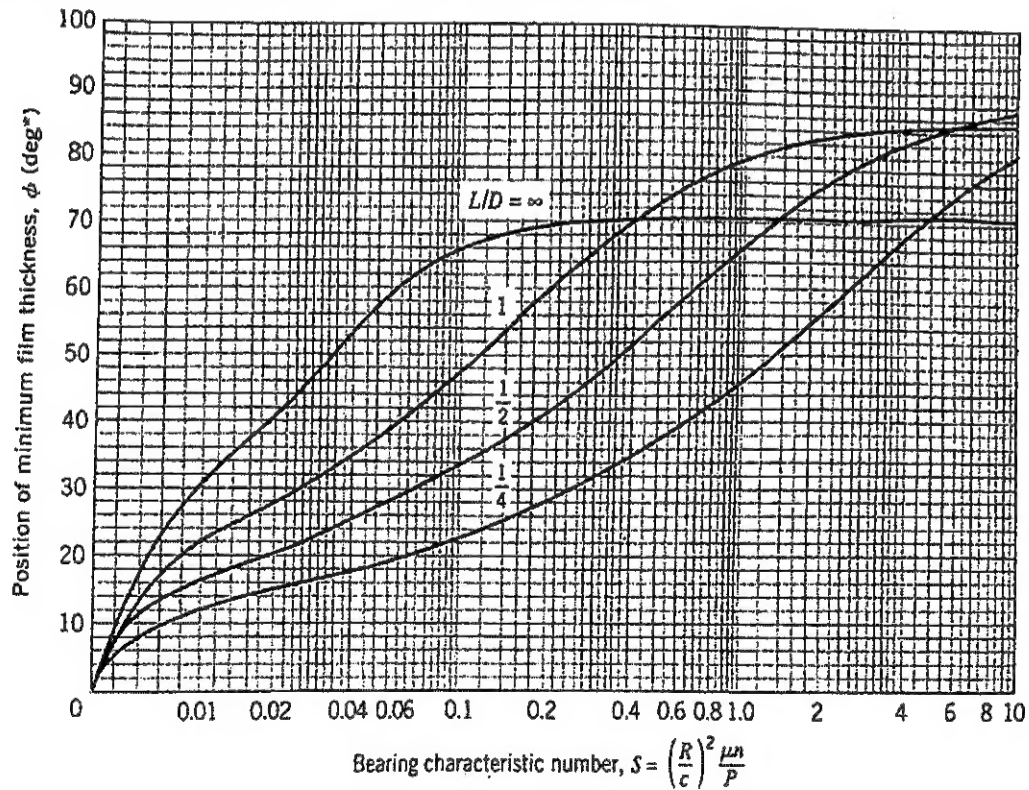
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Chart A8 – Positions of the maximum film pressure and film termination

Bearing characteristic number, $S = \left(\dfrac{R}{c}\right)^{2} \dfrac{\mu n}{P}$

End of Paper